Technology and Environmental Performance: Leveraging Growth and Sustainability

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1. Introduction

Whatever one's view of global environmental prospects -- fast worsening or slowly improving -- there can be little disagreement that environmental quality that most people experience -- in Asia, the U.S. or Europe -- still falls vastly short of what most of them want. Though faced with this imperative, the principal decision-makers who control its realization -- i.e., firms and policy-makers -- too often parse the problem as a choice between economic growth today and long-term environmental sustainability. Technology offers a way out of this dilemma. Key to both economic growth and environmentally friendly products, processes and systems, technological change is a neutral motive force that can be channeled toward whatever goals society chooses. So motivated, there is no reason that new technologies cannot effectively co-optimize environmental and economic dimensions.

Technologies that improve environmental quality are hardly new. Indeed, a strong paradigm of what environmental technology is and how to elicit it developed within the OECD nations about 30 years ago. Essentially single purpose, environmental technologies were developed to satisfy regulation-mandated pollution limitations and clean-up after the fact. Rarely did they emphasize *ex ante* design changes that could avoid environmental insult. A global industry with sales of more than $400 billion operates on the basis of this paradigm, with its most buoyant markets today in industrializing countries where environmental policy is taking root.

From the benefit of experience, the pollution-abatement and clean-up paradigm can be judged a useful, but limited, first-generation approach. For the longer-term, however, its tendency to prolong the lives of inherently dirty or resource-intensive technologies makes it a doubtful platform from which to launch an environmentally sustainable society -- or to promote economic growth. Happily, a different approach -- clean, shared growth -- is beginning to be envisioned. Dematerialization of industry, intelligent process controls, eco-friendly products, alternative agriculture, and industrial firms whose environmental and economic agendas coincide are some of its elements. To achieve this transformation of technology, a parallel transformation must be forged in the realm of public policy: environmental policies reinvented and merged with polices toward industrial technology and investment, cast as a catalyst for technological change.

The essential question in this paper is: What are the prospects and possibilities for an environmental technology transformation in Asia? Because no data speak directly to the point, its answers can only be suggestive, not definitive. It is clear, however, that the potential and the stakes are enormous. Asia's population, economic growth and increasing environmental footprint make it perhaps the most important pivot on which the world's environmental future will turn. And while Asian environmentalism will strengthen, it is by no means certain what form it will take. In neither Asia nor the OECD countries has the character of environmental technology yet focused on long-term investments that can prevent pollution, cut resource-intensity and design for the environment. This paper argues that Asia's high growth/high capital investment pattern -- whether or not they recur -- coupled with its technical capabilities, economic and institutional structures, remain poised to realize this potential: a fundamentally different approach from the technology retrofit that has characterized environmental policy in the OECD. To define and achieve it will require important changes in perspective and practice, both in Asia and among the OECD nations, who are inevitable partners in the endeavor.

The discussion begins with a review of technology's critical role in achieving environmental quality and economic growth. It then charts the diverse types of technological change and proposes three policy imperatives that employ technological change as a force for environmental improvement. After reviewing pivotal features of the Asian situation, it proposes a more specific package of short and long-term environmental technology policies.

2. Technology: the Critical Variable

One way of looking at the relationship between human activity and the environment is to conceptualize it as a mathematical identity. Seen thus, aggregate environmental impact becomes a function of the total number of people, the amount of their economic activity per capita, and the intensity of environmental insult that their patterns of production and consumption imply. Expressed formulaically, the relationship is usually stated[1]:

$$\text{Pollution} = \frac{\text{Pollution}}{\text{GNP}} \times \frac{\text{GNP}}{\text{Population}} \times \text{Population}$$

Naturally, this identity is only an abbreviated shorthand; and naturally, it is subject to dispute. The very word "pollution," for example, needs to be expanded into the concept of the total "environmental footprint" of a society's activity, including aspects as diverse as its patterns of resource usage and its destruction of species in natural ecosystems. Similarly, the connection between GNP per capita and the amount and intensity of pollution is much more complex than the equation can express[2]. So too is the dynamic between population growth and economic growth.

In spite of its limitations, the equation still focuses attention on elements that can make a real difference to environmental quality. By reducing it and using slightly different language, these factors come into relief:

$$\text{Environmental Footprint} = \frac{\text{Pollution Intensity}}{\text{Economic Growth}} \times \text{Economic Growth}$$

When one further considers what variables underlie both economic growth and pollution intensity, technology quickly emerges as key. For advanced industrial economies such as the United States, it is well-established that technology is the

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1 The authors are indebted to J. Gustave Speth (1989) for discussion of this identity, and Marian Chertow (1998), both now at Yale University, for work tracing its origin and evolution.

2 The well-established literature on dematerialization in highly industrialized societies, the "reverse Kuznets curve," and Shakeb Afsah's recent work ("Impact of Financial Crisis on Industrial Growth and Environmental Performance," World Bank, July 1998) all speak to this issue.

main source of productivity improvements, without which economic growth would stagnate.[3] In the development model seen in the emergent economies in Asia, assimilation of externally generated technology has been at the core of first-stage growth; creation of technology provides the basis of its continuation.[4]

The impact of technology on the environment emerges as less unidirectional, but no less critical. Early on, environmentalists tended to blame technology for environmental degradation. In a literal sense, the criticism hit the mark: many post-World War II technologies -- synthetic pesticides for example -- appeared to be damaging ecosystems more seriously and faster than traditional agricultural practices. But more subtly, it was soon recognized that the real culprit was poor, ill-informed or misdirected design choices made by humans, rather than anything inherent in technology. Applied correctly, technology is equally the enabler of environmental progress: today, for example, the revolution in agricultural biotechnology holds the key eco-friendly pest controls, to pursue but this one case.

While technology is the variable that underlies improvements both in economic well-being and environmental sustainability -- and can accomplish the two goals simultaneously -- it is important to realize that it is a dependent variable, with no preordained course. In other words, technology is endogenous, with its form and direction dependent on the signals its creators receive from the cultures, markets and institutions in which they work. Studies tracking technological change in firms have shown this consistently: innovations motivated by market needs, as opposed to laboratory discoveries, are far more successful. Similarly, the alacrity with which firms can produce new technology in response to environmental demands -- either from consumers or regulators -- has been demonstrated repeatedly: the quick rise of substitutes for phosphate-

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[3] There is also a voluminous literature on this point, cited in Picking Up the Pace: the Commercial Challenge to American Innovation, US Council on Competitiveness, Washington, D.C. 1988.

[4] The Korean experience is particularly noteworthy in this regard. See Linsu Kim, Imitation to Innovation: the Dynamics of Korea's Technological Learning, Harvard Business School Press, Boston, 1997.

based detergents in the early 1970s, PCBs in the 1980s and CFCs in the 1990s all make the point.[5]

Technology is thus the variable in the environmental equation that is uniquely flexible, applicable in both the short and long-term, and relatively value-neutral. Population trends, in contrast, obviously offer only a long-term alternative -- and present significant moral dilemmas. And even if reduced economic growth were to represent a pollution-limiting strategy, it would hardly be palatable. In order to consider what possibilities technology offers as a leverage point for both economic and environmental improvement, its pathways, prospects in Asia, and the policies to influence it are examined further below.

[5] George R. Heaton, Jr. " Regulation and Technological Change," World Resources Institute, Washington, D.C. 1990.

3. Pathways of Technological Change and Investment

Technology is the application of science to useful purposes. Though science and technology are often linked, it is a mistake to dwell on this connection, particularly in the Asian environmental context. Science -- new knowledge and understanding -- is not one of the major factors limiting progress toward environmental improvement in Asia. Deployment of better technology certainly is. Beyond this, new science is not always necessary to the creation of new technology, in Asia or elsewhere. Indeed, technological innovation -- which includes both the "hardware" of machines and physical processes as well as the "software" of its management and use -- often takes place absent scientific discovery. The steam engine, for example, predated theoretical understanding of why it worked; and the organization of mass production -- an essential technology of modern life, with profound environmental implications -- drew little, if at all on science.[6]

Technological innovation is the first commercial application of a new technology. In virtually every society today, technological innovation occurs overwhelmingly in private firms -- not in universities, government labs, the military or research institutes. While these institutions are certainly critical in establishing and diffusing the knowledge base on which technological innovation depends, firms are ubiquitously the main generators and deliverers of new technology to society. This statement holds as true for the "environment industry" as it does for more traditional sectors.

Most innovations are not radical leaps forward; in fact, the preponderance are incremental improvements to existing products and processes. If radical innovations typically require systematic and extensive R&D over a long time period, incremental efforts proceed at a more modest, continuous pace. Nor does being innovative require PhD's or other advanced degrees. But what does seem to distinguish innovative from non-innovative firms is the former's attentiveness to the signals sent by the market and society,

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6 The above said, it is true that the connection between science and technology is argued to be closer today than before -- an effect termed "telescoping" of research-intensive technologies, e.g. biotechnology and computers.

their flexibility, and the open, non-hierarchical management style that they combine with technical acumen.

Innovative firms generate technically successful and economically viable new products, new processes and new systems. They may sell them or use them internally. In addition, all firms, innovative or not, are the consumers of innovations. This process, by which innovations spread to subsequent users, is termed diffusion. In successful diffusion, the recipient must discover and capture the value of technology generated elsewhere. This is a fundamentally different process from innovation. The most successful diffusion efforts rest on good information about available technology, adequate capital to acquire it, and the technical resources to adapt it in a new circumstance. In fact, most technologies need adaptive re-working sooner or later; and when adaptation becomes extensive enough, it is virtually indistinguishable from incremental innovation.

"Technology transfer" is another way of describing diffusion. Clearly, there are many modalities of transfer: from technologies embodied in goods and services, to disembodied licenses of intellectual property. Taking a policy point of view, technology transfer is the main mechanism for societies to acquire technologies developed externally. It tends to be visualized as a quicker alternative to innovation, particularly when a country's technical capabilities are insufficient. While this formulation has its appeal, it can also be dangerous to the extent that it gives the misimpression that the societal capability for overall technological development is less than an integrated system involving all stages of the innovation process. Moreover, pursuit of the goal of technology transfer often overlooks the need for capabilities and relationships that can accomplish the hard work of adapting, integrating and renewing technology over the long term in a new context.

In all countries, technological change is closely associated with capital investment. Investment in new plant and equipment both creates demand for technological innovation and affords the locus for its deployment. In Asia, the investment pathway to technological change is particularly critical for two reasons: the combination of extraordinarily high rates of capital turnover, and low rates of indigenous R&D.[7] From an environmental point of view, this situation holds both potential and danger: the opportunity to move environmentally friendly technologies into place faster than elsewhere, via new investment, and the danger of over-reliance on externally generated solutions to local environmental problems.

The last essential point about technological change is that it is driven overwhelmingly by demand. Just as firms that rely on "technology-push" strategies of laboratory-based invention are routinely less successful than those that innovate to suit their customers' needs, so too are national strategies that emphasize increasing the supply of environmental technologies likely to be less successful than those that augment demand for environmental quality. But the concept of "demand," is by no means equivalent to "the market." Indeed, it is clear that free markets will come no where close to producing the amount of environmental quality any society wants, and that governments must therefore augment demand through regulation, information and other means. But from the vantage point of the innovating firm, the source of demand is irrelevant, so long as it presents viable commercial opportunities for new technology to fill.

[7] Of course, rates of R&D vary significantly across the Asian region (see discusssion below), though high rates of investment have been universal.

4. For An Environmental Technology Transformation: Three Imperatives

Diffuse Best Practice

The need for an "environmental transformation of technology" has been apparent -- and advocated -- for some time.[8] One part of the argument rests on a critique of technologies in current use -- consumer products, industrial processes, infrastructure systems -- from the viewpoint of long-term environmental sustainability. Here, little doubt surrounds the premise that the technologies now employed vastly undershoot the environmental performance that would be possible by adopting others, already developed. With air and water pollution levels now worse than any other region, Asia amply illustrates this propostion.[9] Clearly, technical problems are not what is impeding the fuel economy of American automobiles from doubling.[10] Similarly, readily available building products -- from sun-sensitive "smart" window coatings, to long-life bulbs, to standard insulation -- could halve U.S. residential energy consumption[11]; and substitution of electric-arc steel making for the basic oxygen process could move scrap inputs in steel from 30 percent to 100 percent[12]. That these improvements do not occur has little to do with technical capability. The same point can be made about every economy and most economic units: almost none operates at the state of the art.

Diffusion is thus the first imperative in an environmental technology transformation. Policies to promote faster, wider diffusion of today's better but unused environmental practices need not focus on the traditional supply-side features of technology policy -- R&D, education of scientists and engineers, etc. Rather, they must increase demand for improved technologies -- through deliberate use of regulation or other industrial standards. They need to decrease

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8 See Heaton, Repetto and Sobin, Transforming Technology: An Agenda for Sustainable Growth in the 21st Century, World Resources Institute, Washington, D.C. 1991.

9 See Table 1 in accompanying paper, "Toward Clean Shared Growth in Asia."

10 For discussion of current research programs with this goal, see Daniel Roos, Frank Field and James Neely, "Industry Consortia," in Investing in Innovation (Branscomb and Keller, eds), MIT Press, Cambridge, 1997.

11 See Kelly, Henry, "Energy and Economic Growth Revisited, " World Resources Institute, Washington, D.C., 1990.

12 Heaton, Repetto and Sobin, 1990, op. cit.

the cost of such technologies relative to their established competitors -- through mechanisms as diverse as taxation and commodity pricing. And they need to facilitate the channels of information and acquisition for the entities that are their consumers.

Incremental Innovation: Rethinking environmental technology

Worldwide sales of the "environmental industry" now amount to over $ 450 billion yearly.[13] While there is not yet a good, internationally accepted definition or data base for the industry,[14] the technologies that the industry sells typically have environmental improvement as their sole purpose. These are commonly categorized into four subgroups: pollution control; damage remediation and restoration; pollution monitoring and assessment; and damage avoidance.[15] Although data are not available to show the breakdown of expenditures among these four categories, it is safe to say that such data would rank them in the order they are listed above, with pollution control the largest, and pollution avoidance much the smallest.

Another way to view the industry is through the functions it provides, which include services, sales of equipment, and the delivery of environmental resources (water, clean energy, recovered materials). Here, the data are better, as shown by the table below, which contrasts revenues of the industry in the U.S., Europe and Japan.

The data in the table support a number of important points about the character of environmental technology within the OECD.[16] Most tellingly, one sees that only a trivial amount -- no more than 0.5% -- is prevention-oriented. In all three venues, water treatment works and utilities absorb about 30% of the

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[13] U.S. Department of Commerce, Office of Technology Policy, <u>The U.S. Environmental Industry</u>, Washington D.C., 1998.

[14] Work on this issue has been episodic, but continues at the OECD and the US DOC. . See particularly Office of Technology Assessment, <u>Industry, Technology and the Environment</u>, January 1994.

[15] National Science and Technology Council, <u>Technology for A Sustainable Future,</u> Washington, D.C., July 1994.

[16] It should be noted that while the table only covers one year and two sites, data do exist over time for the US, Japan, Europe and Asia. Asian data are presented below

total. Beyond this, the pattern of expenditure derives from the regulatory regimes that are ubiquitously based on pollution control standards for individual media: air , water, waste. Naturally, there are some differences in emphasis. The U.S., for example, spends a considerably greater percentage on air pollution than any other region. And its consulting, engineering and remediation services outpace the others. Japan focuses on solid waste management much more heavily than the other regions, and Europe and Japan both emphasize resource recovery more than the U.S.

Revenues of the Environmental Industry: US, Europe, Japan 1996

	US		Eur.		Japan	
	$bill.	(%)	$bill.	(%)	(%)	$bill.
Equipment						
Water and Chemicals	16	9.3	2.7	7.9	9.3	2.7
Air Pollution Control	14	9.0	7.3	5.5	3.3	3.8
Instruments, Info.	1.8	1.0	1.6	1.2	1.0	1.1
Waste Management	10.7	6.2	9.1	6.8	8.6	9.9
Process and Prevention	0.9	0.5	0.5	0.4	0.5	0.6
Services						
Solid Waste Mgmt.	32.7	19.0	29.5	22.1	29.6	34.0
Hazardous Waste Mgmt.	5.9	3.4	5.2	3.9	3.8	4.4
Consulting, Engineering	14.2	8.3	8.4	6.3	1.1	1.3
Remediation	8.3	4.8	3.7	2.8	1.1	1.3
Analysis	1.2	0.7	1.0	0.7	0.5	0.6
Water Treatment Works	24.6	14.3	21.8	16.3	9.6	11.0
Resources						
Water Utilities	27.0	15.7	19.7	14.8	12.2	14.0
Resource Recovery	11.6	6.8	13.6	10.2	9.2	10.6
Environmental Energy	1.4	0.8	1.5	1.1	1.0	1.1
Total	171.7	100%	133.4	100%	87.1	100%

Source: US Department of Commerce, 1998, with data from Environmental Business International

Historical data such as those in the table above do not necessarily indicate future directions. Although data on patterns of environmental industry R&D would go far toward showing the trajectory of environmental technology, these are not yet available. A few facts are known, however. First, the industry's R&D as a whole is very low in comparison to other technology-intensive sectors, and it is highly concentrated in a few areas.[17] In addition, throughout the 1990s, the stock market performance of the U.S. environmental industry has significantly underperformed industry averages, and the amount of venture capital investment has fallen by a factor of ten.[18] Particularly in the so-called "valley of death" between the generation of a new idea and its commercialization, financing for new environmental technology has been in extremely short supply.[19]

The above notwithstanding, the trajectory of environmental technology development today should not be viewed in entirely negative terms. On the contrary, particularly among the major "polluting" sectors -- chemicals, paper and pulp, resources-extraction, large-scale manufacturing, electronics, etc. -- there appears to have been an important change in mentality and in internal environmental practice: acceptance of environmental sustainability as a core mission of the company, whether in domestic or foreign investment.[20] Evidence of what this means for the process of technological innovation -- though almost entirely anecdotal -- is nevertheless telling. Major firms in the US, for example, report the transformation of their R&D processes as they move toward the integration of environmental goals with overall firm strategy.[21] Policy experiments deliberately designed to encourage technological innovation have proliferated in the US and Europe, with significant success.[22]

There is also some evidence of an emergent new approach to the design of environmental technology. For example, a major survey of the environmental

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[17] DOC, op. cit

[18] Ibid

[19] Technology for a Sustainable Future, op. cit.

[20] Bruce Smart, Beyond Compliance, World Resources Institute, Washington, 1992.

[21] Heaton, Repetto and Sobin, Backs to the Future: US Government Policy Toward Environmentally Critical Technology, World Resources Institute, Washington, D.C. 1992.

[22] Vicki Norberg-Bohm, "Stimulating 'Green' Technological Innovation: An Analysis of Alternative Policy Mechanisms, MIT, Environmental Technology and Public Policy Program, 1997. Robert P. Anex, "Stimulating Innovation in Green Technology: Policy Alternatives and Opportunities," Science and Public Policy Program, University of Oklahoma, 1999.

industry by the US Department of Commerce has shown that the market for "tacked on" pollution control equipment and waste management services appears to be in long-term decline. Taking stock of this situation, the industry has come to believe, according to this survey, that its best prospects lie in a three-part "reinvention" in which it would:

- sell value, not only technical "fix-its"
- deliver total resource productivity rather than environmental control
- integrate environmental management with customers' overall business strategy.[23]

Realizing this approach would represent a major rethinking of the environmental technology paradigm of the last thirty years.

Still, the compelling conclusion from trends to date is that the environmental business in the OECD has been structured largely as a technology retrofit exercise with a particular, limited purpose: compliance with regulation. The corollary is its lack of consonance with the larger dynamic of technological change in the firms that are its clients. If these trends were unfortunate in the OECD context -- prolonging the life of old technology rather than transforming it -- they may prove disastrous if applied to Asia. Whether the economies of Asia revert to high growth or not, the imperative will still be to integrate environmental and growth objectives. If the dominant paradigm of pollution control technology from the OECD is transferred, this kind of cooptimization will not be possible, and environmental technology will continue to be placed outside of the mainstream of industrial development.

Radical Change: Harness emerging technology

The third imperative for an environmental transformation of technology is to harness the potential of emerging technological revolutions -- information technology , biotechnology and new materials -- in ways that promote environmental sustainability. In each case, their potential is enormous: intelligent manufacturing systems with zero-waste; pest-resistant crops that

[23] DOC, Executive Summary, p. I-19

eliminate the need for chemical pesticides; materials designed for total recyclability.[24] Throughout the OECD countries, an increasing percentage of private investment is moving toward these "high technologies," and public R&D programs are increasingly focused on their promotion.[25] The argument is only just beginning to be made that without the kinds of radical innovations these technologies hold, progress toward an environmentally sustainable society will be marginal.[26]

Efforts to tap the potential of these technologies for environmental improvement have only just begun. Japan has probably gone farthest in terms of funding, with the inauguration some five years ago of RITE (the Research Institute for Innovative Technology for the Earth), the world's largest environmental technology research facility,[27] The European Community has recently made the environment a major feature of its technology promotion "plans."[28] In the US, the Clinton-Gore Administration proposed a large-scale Environmental Technology Initiative (ETI) early in its first term, but this is now largely moribund.[29]

Without doubt, virtually all of the R&D and the radically new innovations arising from these fields will continue to be located in the OECD countries. However, their eventual diffusion into the Asian context is a matter of equal importance. Thus, the technology and environmental policies throughout Asian countries could benefit enormously over the long term from technical capabilities that focus on the application of these emerging technologies in the Asian context.

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24 Backs to the Future, op cit.

25 George R. Heaton, Jr., "High Technology Programs in the US, Japan and Europe," Report to the OECD Directorate of Science, Technology and Industry, Paris, 1997.

26 See Norberg-Bohm and Anex, op. cit

27 Heaton, OECD, op. cit

28 Ibid

29 George R. Heaton and R. Darryl Banks, "Toward a New Generation of Environmental Technology," in Investing in Innovation, 1997, op. cit.

5. Pivotal Underpinnings of Technolgical Change in the Asian Situation

Aptitude for Change

As the countries of Asia enter the 21st century, their economic prospects are far from clear, either in the aggregate or individually. By 1997 only Singapore and Taiwan were continuing to increased the rate of GDP growth. Significant variability had begun to surface as well among previously similar situations. Certainly, what happens to the pattern of GDP growth in the Asian region will have important implications for the environment. Plausible arguments can be made both ways: either that slowed growth will slow environmental degradation, or that hard economic times in fact bring neglect of the environment in their wake.[30] The point here is not to predict or analyze this relationship. Rather, it is to ask what legacy the past pattern of rapid growth implies for environmental improvement through the mechanism of technological change.

One of the benefits of fast economic growth in Asia is an almost-tautology: the aptitude for growth and change. In fact, however, societies exhibit different capabilities and proclivities for change, and these are, to some extent, learned characteristics. In many Asian societies, the 1980s and 90s forced public institutions, private firms and individuals to become adept -- through experience -- at the skills and activities that confer success in a rapidly changing economy. Across the region, yearly GNP growth has averaged more than 5% for thirty years. Export production has been coninuously recalibrated to suit new market needs; foreign capital and technology have revolutionized the structure of industry. Indeed, it is ironic that Japan, the region's first-mover, may now be the country most resistant to change.[31]

Another factor that reveals the aptitude for change is the relationship between GDP and gross domestic investment. As the table below indicates, two basic tendencies can be seen: a high and increasing rate of domestic investment

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[30] These arguments are treated in the "meta-paper" and will not be addressed here.
[31] Indeed, the core technology policy debate in Japan today revolves around exactly this issue: has Japan become so conservative and rich enough that its capability for growth and change has atrophied?

among the less-developed countries (i.e., Indonesia, Malaysia and Thailand); and a high but decreasing rate of domestic investment among the more-developed countries (i.e. Japan, Taiwan and Singapore).

The domestic investment data in the table extrapolate to what is already well-known: the extraordinarily fast rate of capital turnover all Asian societies were experiencing before the recent economic crisis. Since capital investment is one of the primary vehicles for technological change (typically, diffusion) these numbers also offer a surrogate measure for the habitual willingness with which these societies accept new technologies.

Ratio of Gross Domestic Investment to GDP in Asian Countries (%)

	1980	1985	1990	1992	1994	1996	1997
Indonesia	20.9	23.1	28.3	25.8	28.3	31.1	n.a.
Malaysia	30.4	27.6	33.6	35.1	38.7	41.5	42.8
Thailand	29.1	28.2	41.1	40.0	41.2	41,7	35,0
Taiwan	33.9	19.1	23.1	24.9	24.1	21.2	23.4
Singapore	46.3	42.5	39.5	36.4	32.2	34.1	36.1
Japan	32.2	28.2	32.3	30.7	28.7	29.6	31.3

Source: Asia Pacific Profiles, Asia Pacific Economic Group, 1998
International Financial Statistics Yearbook, IMF, 1998

Another well-known consequence of the pattern of growth in Asia is a major structural shift in the economy: away from traditional agricultural pursuits and toward industry and services. The combined scenarios of high capital investment and sectoral shifts toward industry have produced the well-known increases in the "toxic intensity of production" that are at the root of today's Asian environmental crisis.[32] On the other hand, Asia's high rates of capital investment and sectoral shifts also afforded the theoretical opportunity --

[32] See, primarily the World Bank (Hemamala, Martin, Singh and Wheeler) for publications on the Industrial Pollution Projection System, and Heaton, Banks and Ditz, Missing Links: Technology and Environmental Improvement in the Industrializing World, World Resources Institute, Washington, D.C. 1994.

surpassing that of any other region -- to turn new investment in an environmentally friendly direction. If such rates of growth and investment return, then the same opportunity reasserts itself. Assuming that they do not, however, the moment of opportunity has not disappeared. Because the Asian economies and societies have developed an extraordinary capability to accept technological and economic change as the usual case, the legacy may leave them with is an equal cultural capability to implement an environmental transformation.

Technical Capacity Understated by Conventional Measures

Conventional measurements of national scientific and technological capabilities tend to focus on a few well-known inputs, of which R&D in relation to GDP is the most-cited. For the Asian region, however, such data are both an imperfect and misleading characterization of the capabilities which can be applied to the process of technological change, particularly in the case of environmental technology.

The table below compares R&D/GDP ratios for the U.S., Japan and four Asian countries. Although 1990 is the last year for which comparable R&D data are available across the countries listed, the 1995 estimates are reliable.

Research and Development (R&D) as a Percentage of GDP, selected countries

	Japan	Singapore	Korea	Taiwan	Indonesia	US
1980	2.0	0.3	0.6	0.7	0.3	2.3
1985	2.6	0.7	1.4	1.0	0.3	2.7
1990	2.9%	0.9	1.9	1.7	0.3	2.6
1995 (est)	2.8	n.a.	2.8	1.8	0.3	2.5

Sources: Human Resources for S&T, The Asia Region, NSF 1993
S&T Indicators for Indonesia, BPPT, 1993
S&T Resources of Japan, NSF, 1997
Science and Engineering Indicators 1998, NSF, 1998

The Asian R&D scenarios present a three-tiered pattern over time: highly R&D-intensive societies, such as Korea and Japan, now essentially on a par with the US and Europe in the level of investment; increasing R&D intensity in Singapore and Taiwan, bringing them to a moderate level by worldwide standards; and continuing low R&D in societies such as Indonesia. Particularly when coupled with another important trend -- increasing technology transfer within Asia (see discussion below) -- the tiered structure of Asian R&D suggests that a new pattern of intra-regional specialization may be emerging in technology development and diffusion. In contrast to past reliance on the U.S. and Europe as the source of new technology, the high-R&D Asian societies may well become independent sources of technology for those that are less R&D intensive. Such a pattern could have significant implications for the design of environmental technology.

A well-recognized limitation of R&D data is that they only measure organized research and development. To the extent that technological change relies on less-formal activity than R&D and focuses on incremental innovation and adaptation rather than radical technical breakthroughs, measurements of national R&D may understate a country's true capability. For the low-R&D countries of Asia effective levels of technical capability may higher than this conventional measure portrays.

The most important input to the process of technological change is certainly technically skilled people, whether or not they are engaged in R&D. Numbers of technical degree recipients within a given population are typically used to tally this input. As the following table indicates, the proportion of master's and doctor's degree recipients in Japan, Singapore, Korea and Taiwan equals or exceeds that in the U.S., thus giving these countries exceptional human capabilities in technology development.

Masters and PhD Recipients per million people, selected countries

	Japan		Sing.		Kor.		Taiw.		US	
	M.	PhD	M.	PhD	M.	PhD	M.	PhD	M.	PhD
1975	121	41	8	3	n.a	n.a	n.a	1	173	19
1980	131	54	19	8	58	5	56	2	162	17
1990	209	88	54	22	145	22	184	15	150	17
1994	292	91	n.a.	n.a.	n.a.	37	n.a.	28	169	18

Sources: Human Resources for S&T, The Asia Region, NSF 1993
S&T Indicators for Indonesia, BPPT, 1993
S&T Resources of Japan, NSF, 1997
Science and Engineering Indicators 1998, NSF, 1998

Another important educational phenomenon for Asia is the numbers of students who receive degrees abroad in science and engineering. By the early 1990s, more than 125,000 Asians were receiving such degrees in the U.S. This figure, which tripled during the decade, represented about two thirds of all American science and engineering degrees given to foreign students and about one quarter of all such degrees. While the vast majority of these degrees went to citizens of China, Japan, Taiwan, India and Korea, other countries in the region were not unrepresented.[33]

What is less appreciated is the augmentation of technical ability that will result from dramatic increases in Asian students going to Japan. Recruitment of Asians to Japan through the provision of generous scholarships has become a Japanese priority, with the goal of 100,000 such students by the year 2000. Most of these will be drawn from China, Indonesia, Thailand, Pakistan and Bangladesh. Even now, foreign students, largely from Asia, receive about 40% of Japanese degrees in science and engineering.[34]

Besides serving as an indicator of internal technical capability, the tendency by Asians to study abroad reflects an increasing integration into the world economy and an accompanying reduction of disparities in the level of

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[33] Science and Engineering Indicators - 1996, National Science Foundation, Washington , D.C.
[34] Ibid

science and technology, at least among Asian elites. These phenomena are illustrated by other data as well. One measure of the degree to which Asian individuals and firms can compete at the highest levels is offered by the table below, which tracks U.S. patents granted to Asian inventors. While Japan vastly outpaces all other countries (accounting for about half as many patents as Americans) Korea and Taiwan are also significant presences, and the remaining countries listed -- Indonesia, Malaysia and Singapore -- have all made dramatic increases from a low base.

US Patents Granted to Inventors from Asian Countries

	Japan	Sing.	Korea	Taiwan	Indon.	Malay.	US
1971	4006	4	2	0	2	0	55467
1981	8387	4	17	80	1	1	38019
1991	21027	15	404	904	2	12	47569
1997	24314	111	1828	2490	12	26	57876

Sources: Asia's New High-Tech Competitors, NSF, 1995
Science and Engineering Indicators 1998, NSF
Patent and Trademark Office Review, FY 1997, US DOC 1998

The table below -- showing ratios of investment abroad to GDP in five countries -- represents another important indication of technical capability in Asian countries and their integration with the external technical community. Although in each case the level of external investment is small, it is provocative to note that Thailand, Korea and Taiwan all exceed Japan and rival that of the US. The table's data need also to be informed by the fact that about half of the investment leaving Asia targets developed countries. The conclusion that emerges is that a significant segment of the Asian investment community is able and willing to accept the modes of business in North America and Europe -- including current environmental practices.

Direct Investment Abroad/GDP (%)

	1980	1985	1990	1992	1994	1996	1997
Thailand	n.a.	n.a.	0.2	0.1	0.3	0.5	n.a.
Taiwan	0.1	0.1	3.3	0.9	1.1	1.4	1.6
Korea	0.0	0.0	0.0	0.4	0.7	0.9	1.0
Japan	0.2	0.5	1.7	0.5	0.4	0.5	0.5
US	0.6	0.3	0.5	0.7	1.0	1.2	n.a.

Sources: Asia Pacific Profiles, Asia Pacific Economics Group, 1998
Balance of Payments Statistic Yearbook, IMF 1997

Increasingly Regional Technology and Investment

One of the trends that emerged in Asia during the 1980s was a movement toward stronger regionalism, in which flows of technology and investment inside the region derived increasingly from other countries within the region. This trend is highlighted in the table below, which tracks the origin of foreign direct investment.

Perhaps the most interesting phenomenon the data in the table point to is the rise of NIEs as a source of capital in Asia. This is particularly true for Malaysia, the Philippines, Thailand and Indonesia, where capital from the NIEs accounts for a third to half of all FDI. The relative decline of the U.S. as a source of FDI is also apparent; only in Singapore and Korea was it still the prime investor in 1990. In many countries, Japan became an increasing investment presence during the 1980s. When Japan's and the NIEs' FDI contributions are aggregated the reliance of Asia on itself -- not the US and Europe -- becomes all the clearer.

Origins of FDI in selected Asian countries (%)

		US %	Japan %	NICs* %
Malaysia	1986	3.3	11.1	23.7
	1988	12.6	27.9	35.3
	1990	6.2	31.8	39.9
Philippines	1986	28.7	28.5	10.2
	1988	12.6	27.9	35.3
	1990	6.2	31.8	39.9
Taiwan	1986	19.5	36.0	9.2
	1988	12.7	40.7	12.2
	1990	25.9	39.7	11.9
Thailand	1986	7	43.2	15.7
	1988	10.8	49	27.4
	1990	7.7	19.2	62.2
Indonesia	1986	16	40.6	10.5
	1988	16.6	5.8	34.7
	1990	1.7	25.6	29.7
Korea	1986	35.4	38.9	4.5
	1988	22.2	54.3	1.2
	1990	39.5	29.3	2.6

* Taiwan, Singapore, Hong Kong, Korea

Source: Nomura Research Institute and Institute of Southeast Asian Studies, 1995

The implications increasing regionalism may hold for environmental policy are provocative. If Japan and other Asian sources increase their dominance in capital investment, then it stands to reason that the paradigm of their environmental policies -- and technologies -- will provide an increasingly important model as well. If their approach essentially replicates that taken earlier in the U.S. and Europe, then the same pattern of environmental technology development can be expected throughout Asia. At the same time, however, newly important Asian sources of capital may also be the lever to a transformed approach in the region.

The Direction of Environmentalism

One way to envision the future of environmental investment in Asia is to analogize from to the experience of other countries and regions. The table below compares the situation in a number of countries at the beginning of the 1990s. It shows that large OECD countries -- Germany, the UK, Japan -- were typically spending about .8% of GDP on environmental investments. Korea and Taiwan were spending a considerably smaller percentage at this point, while the US and Singapore spent considerably more.

Environmental Expenditures in Selected Countries

Country	Year	%GDP
Japan	1990	0.81
Germany	1990	0.89
UK	1990	0.84
Korea	1991	0.25
Taiwan	1991	0.51
Singapore	1992	1.23
US	1990	1.36

Source: US Congress, Office of Technology Assessment

The point-in-time data from the table above can be supplemented with predictions of growth in environmental expenditures, presented in the table below. For Europe, the U.S. and Japan, the table shows that environmental expenditures appear to have reached a plateau, and are in fact growing slower than GDP. While Latin America is significantly increasing environmental expenditures, the area of extraordinary growth is to be found in a tier of Asian NIES -- Hong Kong, Taiwan, Singapore and Korea. These countries are increasing environmental spending even faster than their high rate of GDP growth, having effectively decided to adopt levels of spending for environmental quality on a par with those throughout the OECD.

Projected Growth in Environmental Expenditures (%)

Region/Country	1994-95	1995-96
US	2.7	0.8
W, Europe	2.0	2.8
Japan	1.4	2.0
Rest of Asia	16.3	18.9
Latin America	7.8	12.8

Source: US Dept. of Commerce, 1998

Beyond these data lurk a number of questions that take on the character of imponderables: will the rest of Asia follow the pattern of environmental investment that seems well underway in Korea, Taiwan and Singapore? If so, with what speed? Will the technologies adopted replicate the pollution abatement model in the OECD or proceed in new directions to reduce the environmental intensity of production at its source?

Though there are no data that answer these questions, there are some troubling indications.[35] The following table arrays expenditure patterns for environmental technologies in Asia in 1996 as compared to those in OECD countries. Making aggregations across categories in the table, one sees that over 50% of the total environmental investment in Asia is allocated to the combination of water utilities, water treatment and water equipment and chemicals. This is a considerably larger share than in Japan, Europe or the US, where the same aggregation of categories accounts for approximately one third of the total. In most other categories, environmental technology investment patterns in Asia do not depart strongly from the OECD model. Process and prevention technology, for example, is less than 1% of the total in every region. These data suggest that the focus of environmental investment in Asia is even more strongly on abatement and clean-up -- above all for water -- than was the case in the OECD.

[35] It should be noted that the lack of good studies that track patterns of investment in environmental technology is a serious drawback to analysis in this area.

Little of this investment can be expected to prevent pollution or decrease the pollution-intensity of production.

Comparative Expenditures for Environmental Technology (% of total)

	US		US	Europe	Japan	Asia
Equipment						
Water and Chemicals	9.3		9.3	7.9	9.3	14.1
Air Pollution Control	9.0		9.0	5.5	3.3	4.7
Instruments, Info.	1.0		1.0	1.2	1.0	1.0
Waste Management	6.2		6.2	6.8	8.6	6.8
Process and Prevention	0.5		0.5	0.4	0.5	0.5
Services						
Solid Waste Mgmt.	19.0		19.0	22.1	29.6	17.8
Hazardous Waste Mgmt.	3.4		3.4	3.9	3.8	2.6
Consulting, Engineering	8.3		8.3	6.3	1.1	4.2
Remediation	4.8		4.8	2.8	1.1	2.1
Analysis	0.7		0.7	0.7	0.5	0.5
Water Treatment Works	14.3		14.3	16.3	9.6	14.1
Resources						
Water Utilities	15.7		15.7	14.8	12.2	23.6
Resource Recovery	6.8		6.8	10.2	9.2	5.8
Environmental Energy	0.8		0.8	1.1	1.0	2.1
Total	100%		100%	100%	87.1	100%

Source: US Department of Commerce, 1998, with data from Environmental Business International

Of course, it is not surprising that Asian environmental technologies would resemble those elsewhere. As the following table indicates, more than two-thirds of the market for environmental technology in Taiwan consists of imports. Of those imports, about two-thirds originate in the US and Japan. The reliance on OECD nations as a source of technology is likely to be even higher in other parts of Asia, and is likely to remain so. This interconnection establishes a partnership with profound implications for Asia's environmental future.

Taiwan Environmental Technology Market

	1989		1990		1991	
	Mill $	%	Mill $	%	Mill $	%
Total Market	651	100	755	100	923	100
Imports	450	69.7	520	69	620	67
Exports	3	0.3	5	0.5	8	1
Local Prod.	198	30	230	30.5	295	32.5
Import Share						
US				34		
Japan				29		
Germany				17		
Sweden				5		
UK				4		

Source: US Congress, Office of Technology Assessment

6. Policies for Technology Transformation in Asia

Avoiding an Inappropriate Paradigm

Much of the paradigm for environmental policy -- and its implementing technologies -- originated in the U.S. during the 1960s. Looking back to conditions then, one sees an economy at the apogee of a particular production paradigm and industrial structure. Much the same may be said for Europe and Japan: all were manufacturing-based, wedded to large scale mass-production, and dependent on industrial facilities that were often old. The industries at the bedrock of these economies -- automobiles, chemicals, steel, consumer durables -- were resource-intensive, polluting, economically conservative and technologically rigid. The technological revolutions that dominate today's economy -- information, biotechnology, miniaturization -- were then only nascent, and the intense global interconnectedness that now characterizes economies and corporations alike had only begun to unfold.

What did these conditions mean for the design of environmental policy? First, OECD environmental policy through the 70s and 80s was almost entirely a domestic affair: countries establishing their own standards based on local conditions, capabilities and politics. Second, a "command and control" regulatory process set the agenda, relying on a tradition of "rational" government decision-making that emphasized rigorous scientific and economic analysis, large administrative and data resources, and adversarialism, whether intellectual or legal. Third, the implementation of regulation relied overwhelmingly on technological retrofit: the adoption of known or close-to-available technologies that could be integrated into the industrial status quo.

Today, although many in the OECD countries recognize the dysfunctional aspects of environmental policy in terms of its impact on technological change, the policy paradigm is nevertheless hard to shake off: the weight of history, established institutions and a sense of slow, steady progress all militate against major policy change.

In Asia, however, today's circumstances push in precisely the opposite direction. First, Asia's environmental problems are as much the world's as its own. Global warming illustrates this from a purely physical point of view, and the interdependent flow of capital, products and technology makes it an economic reality. The impetus for change will thus arise both from external and internal pressures. Second, the Asian economies are likely to continue to be much more hospitable to structural change -- and much more dependent on new investment -- than was the case within the OECD. Designed-in avoidance of environmental damage can thus assume higher priority. Third, the technical capabilities of Asian societies are not heavily weighted toward R&D and policy analysis, nor are their administrative resources so ample. This suggests that Asian environmental polices cannot rely on the formal, legalistic and technical policy mechanisms common in the OECD. Lastly, the traditional policy and power dynamic in Asia -- in which industrial interests and ministries play a major role -- may well afford a more natural pathway for policies that harmonize environmental and economic goals than was ever the case in countries where these functions have traditionally been divided or at odds.

Structuring the Macro-Climate

Because environmental policies are generally superimposed on a pre-existing policy framework, they encounter a common difficulty: entrenched economic, institutional and policy structures that are at best orthogonal to, and at worst openly in conflict with, their purposes. Such policies form a macro-climate that conditions and channels technology development. Without changes in them, the goal of technological transformation for a sustainable economy will be difficult to achieve.

Many of the most profound hurdles to the commercialization of environmentally superior technologies reside in commodity and resource pricing. Energy prices, though certainly the largest single factor, are far from the only problem. Agricultural subsidies, underpricing of virgin resources and economic disadvantages to recycling all play a part. Even among explicitly environmental policies, the use of pricing schemes to make pollution, resources use, and waste expensive is vastly underutilized. At the other end of the policy scale, lack of an environmental focus in the education of managers and engineers effectively encourages ignoring environmental factors in technology design and investment choices. The skills of environmental analysis and green design -- which are teachable -- clearly offer a key to long-term environmental improvement.

A full discussion of the macro-climate for technological change is far beyond the scope of this paper. The main point of listing some of them here is to emphasize that technological change is as much a function of endemic social features as it is of scientific and technical knowledge, and that these features need to be considered as part of the overall innovation and environmental policy system.

Policies for the Immediate Term: Promote Incremental Innovation and Diffusion of the State of the Art

Technological innovation is both a long-term and a disruptive process. To the extent that it poses radically improved alternatives to the technological status quo, it will eventually drive the technologies that represent the status quo out of use. In the near term, however, the technologies in current use can usually be substantially improved -- if they are challenged.[36] Evidence from various industries in OECD countries makes the case that the source and nature of the challenge is less important than its force -- environmental regulatory pressures, for example, may motivate as effectively as international competition.[37]

What this suggests for an environmental technology policy in Asia is the need for a first-tier strategy to promote environmentally oriented incremental innovations and to diffuse state of the art technologies not yet widely employed. Since the potential supply of such technologies is already ample throughout the OECD, the essence of the strategy in Asia should be demand-side enhancement. Four main elements should have prominence: regulation, information dissemination, enhancing demand through the MNC supplier chain, and technical assistance.

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[36] This point is discussed at some length in James Utterback, Mastering the Dynamics of Innovation, Harvard Business School Press, Boston, 1994. One example is vacuum tubes, which made major improvements in response to the transistor challenge.

[37] These studies, which have surveyed the connection between environmental regulation and technological change in various industries, are surveyed in George R. Heaton, Jr. "Regulation and Innovation: A Scoping Paper," OECD Directorate of Science, Technology and Industry, Paris 1997.

Regulatory commands offer probably the most effective policy mechanism for diffusing currently available technology. From the point of view of fostering innovation, however, regulation tends to entrench the status quo by legal fiat, which can create substantial barriers to environmental innovators. The complex relationship between regulation and technological change has been discussed elsewhere.[38] The essential point here is that regulation needs to target both diffusion and innovation. In the former case, it should be directed at upgrading or eliminating existing environmentally offensive technologies. For new technologies, regulation should create a lenient and flexible climate, thus giving innovators a chance to experiment with new approaches.

Environmental data banks offer another common attempt to increase technology diffusion, through dissemination of information about currently available technologies. While such information has its place, it is not nearly as effective in augmenting the demand for superior technologies as is information about company environmental performance. In the US, for example, the toxic release inventory (TRI) has enjoyed considerable success as a means of demand-enhancement. Some policies in Asia -- notably Indonesia's system of coding corporate environmental performance -- operate on a similar principle.[39] Such efforts need to proliferate and expand.

Technical assistance is frequently seen as a supply-side means of increasing environmental capacity. However, experience with programs that focus on instructing companies about how to implement clean production suggests that this approach is a weak motivator. On the other hand, when technical assistance combines environmental efficiency with improvements in product quality and manufacturing cost, its recipients can become highly

[38] See companion paper on regulatory policy, as well as George R. Heaton, Jr. and R. Darryl Banks, "A New Generation of Environmental Technology," Journal of Industrial Ecology, Vol 2, 1996.
[39] Ditz, Daryl, and Janet Ranganathan, "Measuring Up: A Common Framework for Tracking Corporate Environmental Performance," World Resources Institute, Washington, D.C. 1997.

motivated to undertake a package of improvements.[40] So restructured, technical assistance can become an effective demand enhancement.

A last, and dramatically underutilized, mechanism to increase the demand for environmentally superior technology resides within the multinational corporate community. While MNC's relationships to their supplier chain affiliates have often been seen as a supply-side vehicle for the diffusion of improved environmental technology, much less appreciated -- and potentially more powerful -- is the degree to which they can enhance environmental demand. Given their economic clout, MNC's could improve environmental demand through mechanisms much like those used by government procurement agencies; i.e., promising to purchase goods and services whose environmental characteristics exceeds prevailing norms.

Medium-Term Policies: Green Design of New Technology

All technologies proceed through a design phase, when the possibilities for how to configure them are weighed in terms of functionality and other benefits, as well as against cost and other drawbacks, such as pollution or waste. The design phase is inherently creative, though by no means research-intensive; indeed, good designs may result without any research. It is also when problems can be designed out before they arise. This is the essence of pollution prevention.

One way of looking at the cause of environmental problems in OECD nations is to see them as design failures: an absence of environmental consciousness early enough to avoid damage. The same may be said of Asia today, only moreso. If the pollution-intensity of Asian economies, particularly in the manufacturing sector, is actually getting worse, then clearly, the root failure is in the way products, processes, facilities and systems are being designed.

The pathway to changing the environmentally destructive design paradigm begins with asking who controls it and what motivates them? Three thrusts suggest themselves. First, the design of technologies embodied in

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[40] Experience with AID-supported programs in Chile -- not published -- demonstrated the appeal of technical extension services that promised productivity and environmental improvements for companies.

multinational corporations' new investments deserve special attention. MNCs routinely assert that their investments in developing countries meet "the same" environmental standards as those in the home country. This rubric probably needs to be changed. In fact, it is plausible to maintain that developing country technologies need to be cleaner, given the faster trajectory of pollution-intensity they appear to be on. As importantly, transplanting "the same" technologies as those back home allows for little design on site, and thus frustrates exactly the capability that needs augmentation.

Most Asian governments are already highly attuned to interactions with multinationals. Pushing the MNCs' new investments toward better environmental standards should not represent an excursion into new territory. Nor should it pit one country against the other if it is done publicly. Indeed, the public pro-environmental positions taken by many multinational companies can be leveraged in the effort, as well as the involvement of the NGO community. There is also and important, thus far underutilized, role for OECD governments and multilateral organizations in this arena.

Second, the industrial and environmental policies in the Asian countries need to join hands -- perhaps even be merged -- particularly with respect to domestic investment. U.S. policy structures in particular show the dangers of separating technology, industrial and environmental policy: promotional programs for new technology that underemphasized environmental needs, and regulatory programs that seemed anti-industrial. The Japanese approach may offer a more harmonious mechanism: folding environmental enforcement into an industrial ministry, MITI, that has long been the largest influence on patterns of domestic investment.

Lastly, because design is as much an ethos or mentality as it is a technical enterprise, the sensitivity of designers to the environment must be enhanced. This is basically an educational effort, but one that needs to be undertaken as much by the community of practicing engineers and managers as much as through traditional venues for education and training.

Long-Term Policies: Harnessing Radical Technological Change

Although emergent revolutions in technology -- biotechnology, miniaturization, information systems, new materials -- hold immense applications for environmental improvement, public policy in most countries is hardly coming to terms with them. In the U.S., for example, the vast majority of publicly funded R&D categorized as "environmental" is in fact environmental science, with almost none devoted to technology development.[41] Some other countries may be considering the long-term technological possibilities more systematically. The Netherlands, for example, has a forecasting process -- "back-casting" -- that attempts to infer current actions from future technological prospects; and Japan has mounted the world's largest environmental technology research program in its Research Institute for Innovative Technology for the Earth (RITE).[42]

While R&D programs such as RITE are certainly not a universal approach, this is not to say that other countries should not mount systematic attempts to harness the environmental potential of emergent technology. In fact, technology policies in Asian countries -- notably, Korea and Singapore -- have already demonstrated success in an analogous area: industrial technology.[43] The thrust of such policies historically has not been so much to do research or technology development as to create the capabilities and underpinnings -- technical, legal, institutional, managerial -- that allow each society to internalize and exploit technologies on the horizon. Because the environmental technology policies of Asian countries must largely be implemented as initiatives to reduce the environmental intensity of new investment rather than retrofit of the old, the integration of radically new technological possibilities could comprise an important aspect. Its first step should simply be to establish analytical, information and planning capabilities that will take account of technological trends.

7. Conclusions

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[41] In fact, the dearth of environmental technology development was a main rationale behind the Clinton-Gore Environmental Technology Initiative in 1993, which has largely disappeared. See Heaton and Banks in Investing in Innovation, op. cit.

[42] Heaton, "High Technology Policies," OECD, op. cit

[43] Linsu Kim, op. cit.

In spite of the acclaim innovators receive, there is much to be said for being a "second-mover:" avoiding arduous and expensive R&D, bypassing inevitable mistakes of first iterations, and crafting technologies appropriate to particular circumstances. Policy innovations are no less subject to this dynamic. Applying this precept to environmental policy, the Asian countries are well-poised to benefit from others' history. After 30 years' experience, the virtues and drawbacks of OECD policies have come into relief, and a fertile climate of policy "reinvention" has emerged. The pivotal role of new technology in achieving environmental improvement and economic growth is among its most important realizations.

To create an environmentally sustainable technological trajectory for OECD economies, the immense inertia of mature capital and technology, institutions, policies and slow economic growth must all be overcome. Asian economies -- habituated to change -- present a radically different opportunity. If an increasing intensity of environmental insult is to be reversed, the design and implementation of new technologies will be key. While this imperative does not mean ignoring the need for immediate abatement and remediation of current pollution with known techniques, it does mean relegating the "end-of-pipe" clean-up strategy that has so dominated environmental policy and technology thus far to much lower prominence.

Asian societies can thus chart a new course for environmental policy. Indeed, it may even be counterproductive to speak of environmental policy singly, without reference to the overall "innovation systems" in which new technology is developed, acquired, designed and implemented. Because the innovation system is focused simultaneously on short, medium and long-term change, so too must an environmental technology policy function in all these time frames. As technological innovation is a social phenomenon, the societal levers to influence its rate and direction are many: research and development funding, education, regulation, industrial licensing, and resource pricing offer only a partial list. These and others must be enlisted to make technology a lever for growth and sustainability.

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